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A Greedy Construction Heuristic for the Liner Shipping Network Design Problem

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A greedy construction heuristic for the Liner Service Network Design Problem

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Outline

1. The Liner Service Network Design Problem (LS-NDP)
2. Methods based on integer and linear programming relaxations
3. LS-NDP as a multilayered Multiple Quadratic Knapsack Problem
4. The greedy construction heuristic
5. Critique of model and method
6. Future work

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Problem definition

The Liner shipping network design problem

Given a complete graph G' between a set of ports P, a fleet divided into vessel classes A and a set of commodities K determine a minimum cost network $G = (V, E)$ consisting of disjoint non-simple cyclic vessel routes to transport the most profitable subset of the commodities.

Characteristics of a service

Figure: Example of a single service

- Cyclic
- Non-simple
- Inbound vs. outbound direction

Characteristics of a network

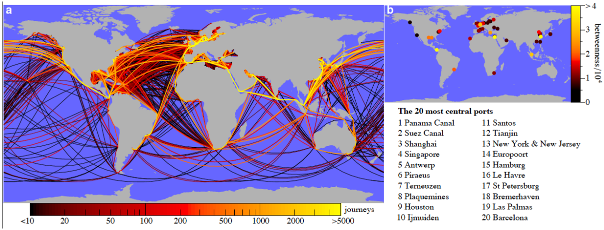


Figure: Network design

- Transhipment of cargo at transhipment hubs and main ports
- Capacity classes: feeder, panamax, super panamax
- Fixed schedule -mainly based on weekly port visits

Selection of previous work

Figure: Transhipment of cargo

Focus:

- Multiple routings (i.e. network design)
- Multiple hubs

Relevant literature:

- #models = #articles
- Main difference: transhipment

Previous work

Article	Method	Optimal	Transhipment	vessels/ports
[1]	Lagrange, Benders	No	No	3v, 20p
[2]	Branch-&-Cut	Yes	Yes, handling cost per container	6v, 20p
[3]	greedy, column generation, Benders	No	Yes, no cost	50v, 10p
[4]	tabu search, LP solver	No	Yes, individual cost per container	100v, 120p

Table: Overview of main articles with multiple route construction

- [1]: Rana & Vickson 1991
- [2]: Reinhardt & Kallehauge 2007
- [3]: Agarwal & Ergun 2008
- [4]: Alvarez 2009

Going global....

Challenges

Scaling to a global liner shipping network
200+ ports, 200+ vessels

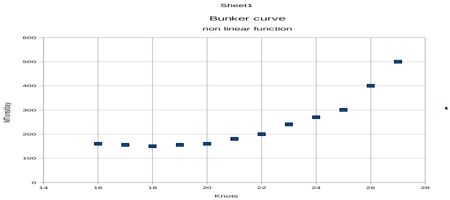
Scalability Issues:

Symmetry: Cyclic Routing Vessel Specs	Large scale multicommodity flow problem

Motivation

Good solutions to the liner shipping network design problem

- Competitive network
- Low cost network
- Inclusion of dynamic non-linear bunker cost calculation
- No optimality guarantee



Work in progress...

- Create a good model including bunker cost
- Build a local search framework (ALNS)

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  1. Construction Heuristics
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  1. Greedy construction heuristic

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  2. Based on a simplified LS-NDP model with simplified cost structures

Model simplifications

Rephrase the problem:

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1. A set of routes

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Multiple Quadratic Knapsack Problem (MQKP)
Routes=Knapsacks
Port calls=items

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Avoid evaluating a large scale multicommodity flow problem

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Profit function, f:
$f(\textit{distance}, \textit{demand}, \textit{transhipment})$

Layer characteristics

Layer	Port types	Distances	Direct	Transport to Hub	Weeks

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Feeder	Spokes	Short	secondary	primary	1-3
	Main ports Hubs				

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Panamax	Hubs Main ports Hubs	Medium	primary	secondary	3-8

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Layer	Port types	Distances	Direct	Transport to Hub	Weeks
Feeder	Spokes Main ports Hubs	Short	secondary	primary	1-3
Panamax	Main ports Hubs	Medium	primary	secondary	3-8
Super panamax	Main ports Hubs	Long	secondary	primary	6-12

Table: Layer classification

Multilayered algorithm

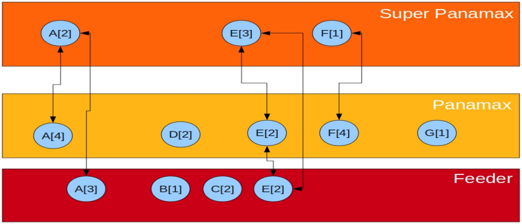


Figure: Multi layered knapsack interpretation of the LS-NDP

- Three layers: feeder, panamax and super panamax
- Port items: Scheduled port visits
- Each layer may have multiple visits to a port

Solve an MQKP for each layer

i	0	1	2
0	0	287	306
1	-25	42	742
2	14	513	0

Table: Profit matrix

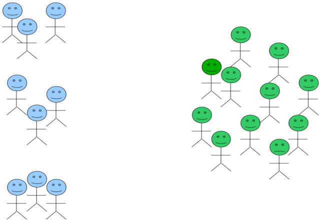
- V_{layer}:items (scheduled port calls with the capacity class of this layer)
- R_{layer}: knapsacks (Services)
- Services are assigned a standard number of vessels
- Number of vessels = Duration in weeks

Specialised MQKP - Mathematical model

$$
\begin{aligned}
& maximize(MQKP) = \sum_{r\in\mathscr{R}} \sum_{i\in\mathscr{V}} \sum_{j\in\mathscr{V}} p_{ij} x_i^r x_j^r + \sum_{r\in\mathscr{R}} \sum_{j\in\mathscr{V}} p_j x_j^r \\
& \text{subject to:} \quad \sum_{r\in\mathscr{R}} x_i^r = 1 && \forall i \in \mathscr{V} && \text{(Mutually exclusive)} \\
& x_i^r x_j^r \geq y_{ij}^r && \forall i \in \mathscr{V}, j \in \mathscr{V}, r \in \mathscr{R} && \text{(Activate edge variable)} \\
& \sum_{j\in V} y_{ij}^r - \sum_{j\in V} y_{ji}^r = 0 && \forall i \in \mathscr{V}, r \in \mathscr{R} && \text{(Cyclic)} \\
& \sum_{j\in V} y_{ij}^r \leq 1 && \forall i \in \mathscr{V}, r \in \mathscr{R} && \text{(Simple)} \\
& u_i^r - u_j^r + y_{ij}^r \sum_{i\in V} x_i^r \leq \sum_{i\in V} x_i^r - 1 && \forall i \in \mathscr{V}, j \in \mathscr{V}, r \in \mathscr{R} && \text{(Connected)} \\
& \sum_{i\in V} \sum_{j\in V} y_{ij}^r (t_{ij} + t_i) \leq \sigma(C_a) && \forall r \in \mathscr{R}_a, a \in \mathscr{A} && \text{(Duration)} \\
& x_i^r \in \{0,1\} && \forall i \in \mathscr{V}, r \in \mathscr{R} \\
& y_{ij}^r \in \{0,1\} && \forall i \in \mathscr{V}, j \in \mathscr{V}, r \in \mathscr{R} \\
& u_i^r \in \mathscr{Z}^+ && \forall i \in \mathscr{V}, r \in \mathscr{R}
\end{aligned}
$$

Quadratic objective function - heuristic solution method

Greedy parallel insertion



The football teaming principle

The knapsacks take turn at choosing the most profitable item among the remaining items

- Principle: parallel insertion
- Motivation: Distribution of difficult items

Algorithm

GREEDYCONSTRUCTION (*instance*)

```
layers ← FLEETTOLAYERS(instance)
SCHEDULETOITEMS(instance, layers)
profitIncrease ← TRUE
for each layer ∈ layers
    do MAKEKNAPSACKS()
       while (V_layer ≠ ∅ ∪ profitIncrease )
           do profitIncrease ← FALSE
              for each r ∈ R_layer
              best ← NULL
              bestValue ← 0
              for each i ∈ V_layer
              deltaValue ← Σ_{j∈r} p_ij
              if (deltaValue > bestValue)
                then
                     bestValue ← deltaValue
                     best ← i
       if (bestValue > 0)
         then
              profitIncrease ← TRUE
              UPDATEDEMANDMATRICES(knapsack, best)
              r ← best
              V_layer ← V_layer \ best
```

Results

- Solve an instance of 234 ports and roughly 14000 demands in 33 seconds
- Evaluated by Network specialists at Maersk Line
  1. The routings are overall realistic
  2. Emphasis on direct transportation
  3. Transhipment fascilities are weak
  4. Good basis for a local search

Conclusion:

Good construction heuristic as initial solution for further local search

Critique of the approach

- Not based on the true objective i.e. the MCF problem
- Little interaction between layers
- Only tested on a single instance of the Maerskline network
- No transhipment cost, bunker cost or vessel deployment cost
- Note: Integration in ALNS will provide evaluation of true cost

Future work for MQKP heuristic

- Interaction between layers
- More realistic goal function
  1. Solve uncapacitated MCF
  2. Evaluate the transit times and the potential throughput
- Test on real life data (Benchmark suite in progress)
- Compare results to the network cost of the initial schedule

Future work for ALNS framework

- Fast delta evaluation of multi commodity flow problem
- Destruction/ construction heuristics
- Benchmark suite for Liner shipping

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